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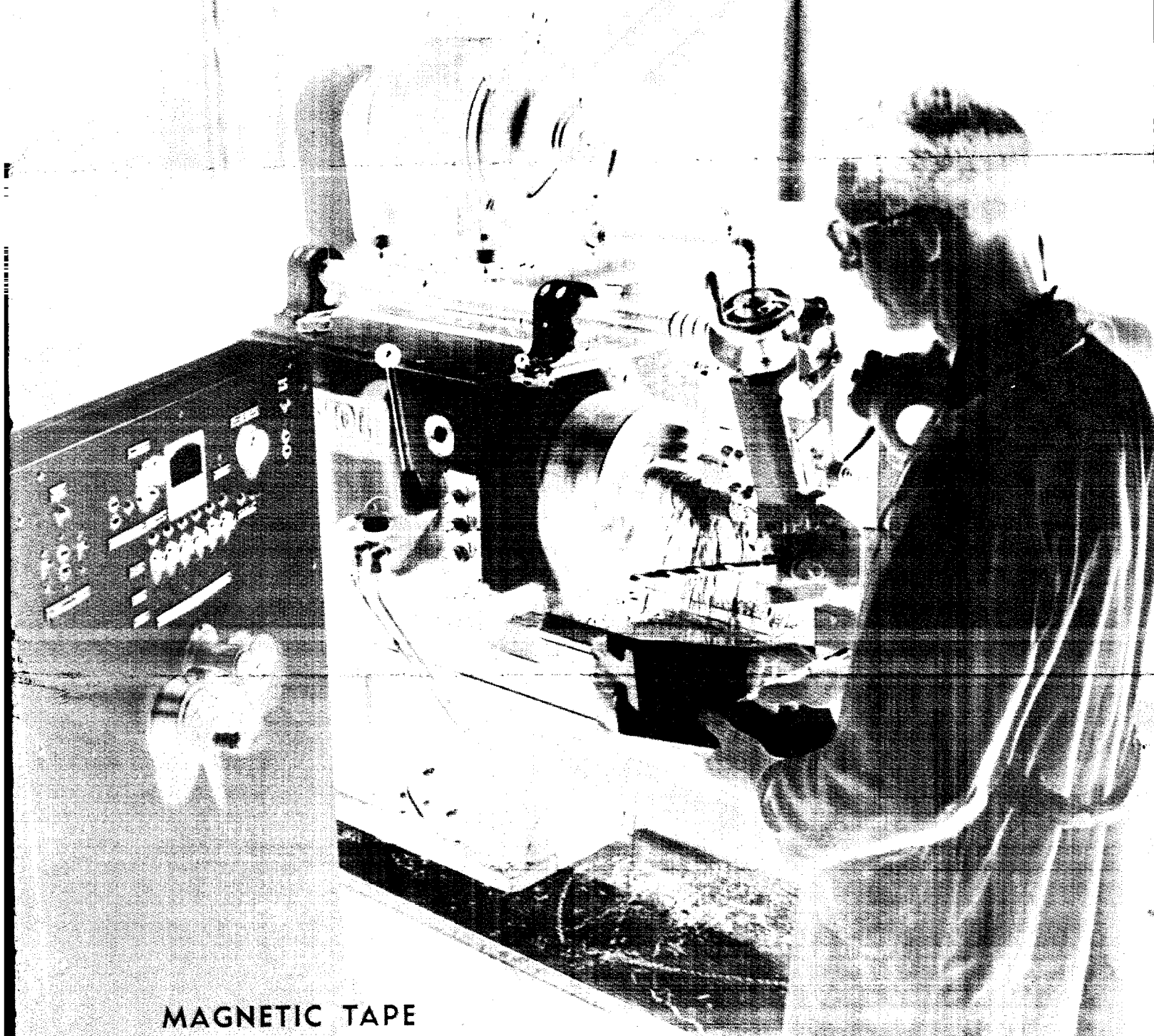
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A M c G R A W - H I L L P U B L I C A T I O N



MAGNETIC TAPE
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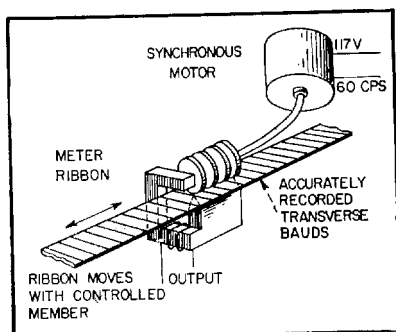


FIG. 3—Secondary signal generator detects position of controlled member

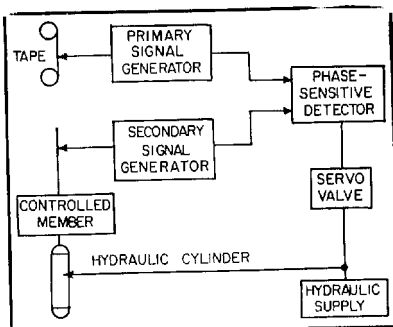
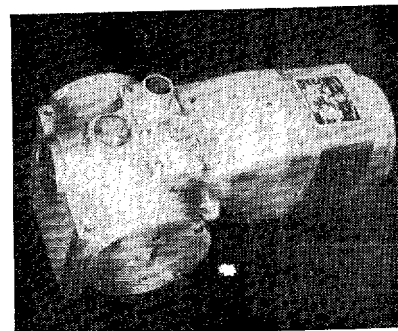


FIG. 4—Block diagram of single-dimension Factrol system



Secondary signal generator has slot on face for tape entry

Machine Tools

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Cutter displacements are accurately recorded as separate tracks on magnetic tape by moving comb linked to cutter by thyatron or other servo drive. Segments of rotating screw act as scanning devices to pick up multi-channel control information during playback

AUTOMATIC machine control incorporating a simple and accurate magnetic recording and playback technique is necessary to realize a unit that can be accepted by industry. In the Factrol system developed for large machine tools, programming information is recorded on a strip of tape. When completed, the tape contains all control signals necessary to start and stop spindle-drive motors, control spindle speeds if multiple tools are used, provide continuous speed control if maximum cutting rates are desired and provide precise displacement control of one or more cutting tools, grinders, drills or cutting torches. Tape signals to control automatic rewind of tape and other auxiliary functions are also recorded.

Basically, a phase-detection system of magnetic-tape playback is provided in conjunction with a conventional hydraulic, Amplidyne or thyatron servo drive. Plastic-backed oxide tape or steel ribbon provides an inexpensive, durable storage medium which is instantaneously ready for playback. It can be recorded, duplicated or erased for reuse by relatively inexperienced personnel. The single

tape provides multiple control tracks for several auxiliary functions as well as the actual tool-displacement control.

The displacement control signal is the part of the recorded information that forms the input to the servo unit and is the most important track or channel on the tape. It is effectively a cam signal because it acts as an integral part of a system that performs the same function as a mechanical cam-controlled machine tool.

Record and Playback

The controlled displacement or cam motion to be reproduced is recorded on the medium by the mechanism shown in Fig. 1A. As the medium is drawn through the transverse magnetizing head, the desired displacement is recorded by moving a comb in the indicated direction. Total displacement is limited only by the physical length of the comb, since an equal number of recorded lines enter and leave the tape as the comb is moved. The polarity and direction of the magnetization are through the thickness of the tape.

Playback of the tape is accomplished by the scanning head shown

in Fig. 1B. The rotary pickup, a part of the magnetic circuit, has a pitch equal to the distance between adjacent teeth on the recording comb. As the rotary pickup revolves, it alternately provides a path of relatively high and low reluctance for the magnetizing pattern on the tape. The resultant generated sinusoidal emf provides the basic control signal for the system. In practice the scanning screw is double-lead and is driven by a miniature 3,600-rpm synchronous motor, resulting in a base frequency of 120 cycles per second. Since the head provides a signal without tape motion, the system does not require tape velocity to maintain locked-in control.

If the tape is moving and displacement velocity is present, the frequency output of the playback head will be increased or decreased, depending upon the relative direction between displacement and scanning-screw motion. In practice, the tape velocity and displacement angle are limited so that the constant-velocity frequencies lie between 60 and 180 cycles per second. The displacement-angle tangent is limited to one-half and tape velocity to six inches per second. This

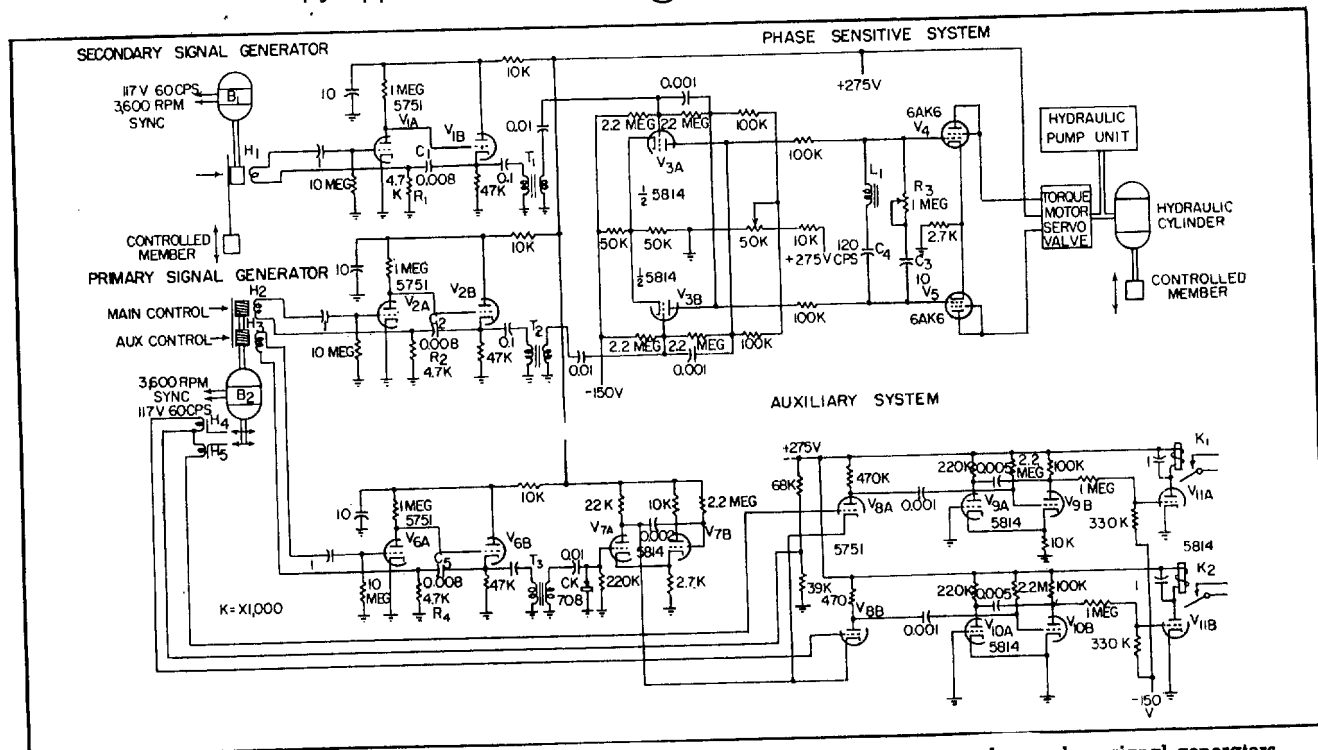


FIG. 5—Circuit diagram of single-dimension system showing sinusoidal inputs from the primary and secondary signal generators

Equalization

An unusual equalization problem presents itself in amplifying the scanning-screw signal. The displacement angle produces an amplitude response versus angle as shown in Fig. 2. This is accompanied by negligible phase shift. A second source of amplitude deviation is due to the conventional 6 db per octave change when the tape velocity includes displacement velocity. In practice, conventional feedback equalization is used to correct the second source of deviation. This provides a minimum of phase shift error under all dynamic conditions.

The output of the pickup head is approximately 0.100 volt rms maximum and the dynamic range (above erased tape) is between 50 and 60 db. The signal contains less than 2-percent total harmonic distortion. One interesting feature of this head is the fact that the gap spacing between the rotating member and the pickup lip is not critical. Since the magnetic circuit is a simple series path, the vertical position of the tape in the gap will result in only second-order changes in output.

Two pickup-head assemblies are used in a single-dimension system. One, the primary signal generator, reads the recorded control signal from the tape, along with any auxiliary control signals. The second unit, the secondary signal generator, detects the position of the controlled member (lathe carriage or milling machine table) by reading the phase of equally spaced bauds recorded on a steel tape called a meter ribbon, shown in Fig. 3. Magnetically, it operates the same as the primary generator except that the axis of the scanning screw is parallel to the length of the meter ribbon. The meter ribbon, when put in place on the carriage, saddle or milling table, becomes a permanent installation. It functions as the accurate comparison link in the servo loop.

Much care is taken to magnetize this tape under uniform ambient temperature conditions, at a temperature that will be a mean value of that encountered in the ultimate location of the machine tool.

Servo System

A single-dimension system is shown in block and schematic form in Fig. 4 and 5. The primary signal generator reads the control-

signal tape. The secondary signal generator gives a reading proportional to the actual position of the controlled member. The outputs of these two units are presented to a phase-sensitive detector and then to a torque motor which controls a hydraulic cylinder to complete the loop.

The sinusoidal signals from the primary and secondary signal generators are amplified by V_1 and V_2 and equalized by networks $R_1 C_1$ and $R_2 C_2$. The signals are then shaped by saturating-core transformers T_1 and T_2 and used to trigger a dual-entry Eccles-Jordan circuit which serves as a phase comparator. The plates of V_3 are adjusted so that the nonconducting and conducting plate voltages will be equally above and below ground potential.

When duty cycles are equal (resulting from 180-deg phase-displaced input pulses) the average d-c voltage at each plate will be zero. The circuit is direct-coupled push-pull into drivers V_4 and V_5 and into the differentially connected torque motor. Integrating network $R_3 C_3$ permits more loop gain as the rate-of-error signal change decreases. The hydraulic servo valve used with the equipment has

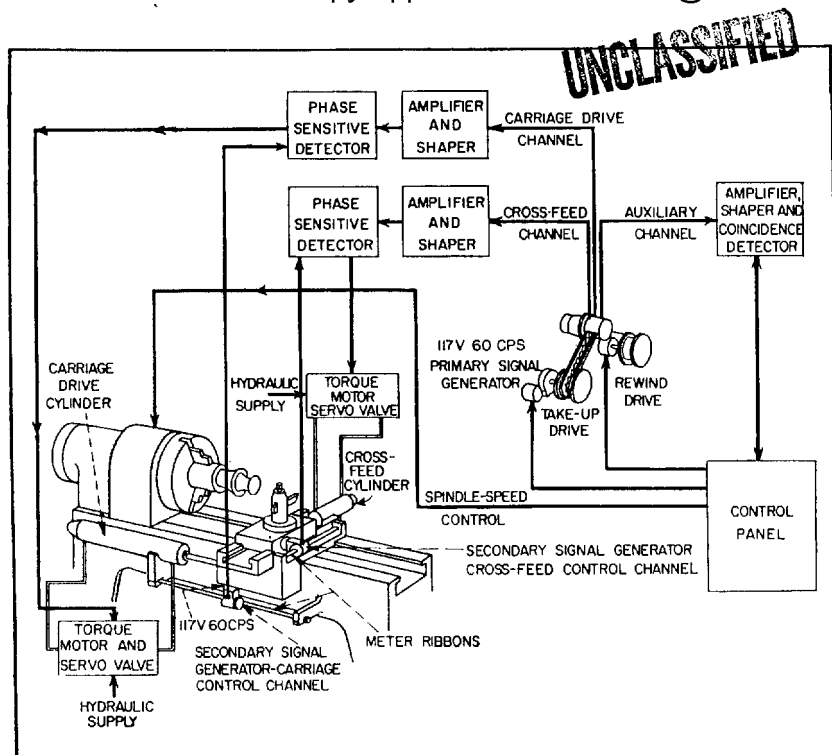


FIG. 6—Simplified diagram of two-dimensional control system applied to a lathe

response characteristics above 100 cycles per second, hence the $L_1 C_1$ network is added for 120-cps fundamental suppression. An error signal of only three degrees provides full power to the torque motors.

Pulse techniques have been employed in the phase detector to avoid effects of tube aging and low-level transient noise conditions. As a secondary advantage, the output of this type of detector is linear from +180 electrical degrees to -180 electrical degrees.

Auxiliary System

The auxiliary pickup head, an integral part of the primary signal generator, is identical with the main signal pickup. The auxiliary signals consist of the conventional parallel-line traces on the tape. However, they occupy only discrete phase-angle positions depending upon the desired number of auxiliary positions.

By a system of coincidence gates, operated by the auxiliary track in conjunction with a pulse-tooth pickup-head group, it is possible to include as many as six auxiliary controls with only one track channel. This operation can be understood by again referring to Fig. 5. When the magnetized insert falls beneath

H_4 , a positive pulse is injected into the grid of V_{8a} . At a time 180 mechanical degrees or 1/120th second later, a magnetized insert falls beneath H_5 and a corresponding positive pulse is injected into the grid of V_{8a} .

The signal from auxiliary head H_5 is amplified by V_6 and equalized by network $R_4 C_6$. It is then shaped and made to trigger one-shot multivibrator V_7 . The normally nonconducting plate of V_{7a} is direct-connected to the cathodes of gate V_8 . When the auxiliary signal is in time coincidence with either H_4 or H_5 , the gate has an output which triggers the associated one-shot multivibrator V_9 or V_{10} . This in turn operates an appropriate relay, K_1 or K_2 . Thus the relays individually stay closed as long as the auxiliary signal remains in phase coincidence with the appropriate pulse.

Operation

The technique under discussion offers a simple means of dynamic control without need for data conversion to digital or other pulse techniques. The latter approach invariably requires continuous tape motion or start-stop circuitry to avoid displacement error in the record. The system described has

continuous closed-loop control, even when the tape is stopped. Thus, the tape can be stopped during certain operations, such as when a drill automatically positioned by the system is drilling through work and requires dwell time.

To conserve tape, the maximum displacement angle is usually used. The maximum angle tangent is 0.5; thus, 30 feet of tape gives a displacement total of 15 feet when meter ribbon pitch equals control-tape pitch.

Additional tape is required for acceleration. The recording process automatically provides constant acceleration (or uniformly increasing velocity) until the maximum displacement angle is reached.

Occasionally the pitch of the recorded bauds on the meter ribbon is changed to a number greater or less than the pitch on the control tape. The resolution accuracy of the system, as well as the ratio of tape length to controlled member displacement, is a function of this pitch ratio. With a pitch ratio of one to one, the overall accuracy from record to controlled member is better than ± 0.001 inch.

Controlled-member velocity is usually varied by changing the speed of the control tape. For multidimensional work and contour control it is often desirable to control member velocity by displacement-angle variation. Also, in multidimensional control, one primary signal generator with multiple pickup coils is used and all dimensional-control channels recorded on one control tape. The width of any control channel is six parallel traces of 0.050-inch pitch for a total of 0.3 inch. To reduce crosstalk, 0.10-inch separation is used between adjacent channels. An individual secondary signal generator is used for each independent dimension control.

The author acknowledges the invaluable assistance given by system inventor Eric Neergaard and his assistant H. Trechsel; J. F. Dundovic of Maico, who contributed heavily on development; the Maico engineering staff; S. Jatras and personnel of the Midwestern Geophysical Laboratories; and D. A. Gerard of DAG Tool and Engineering.

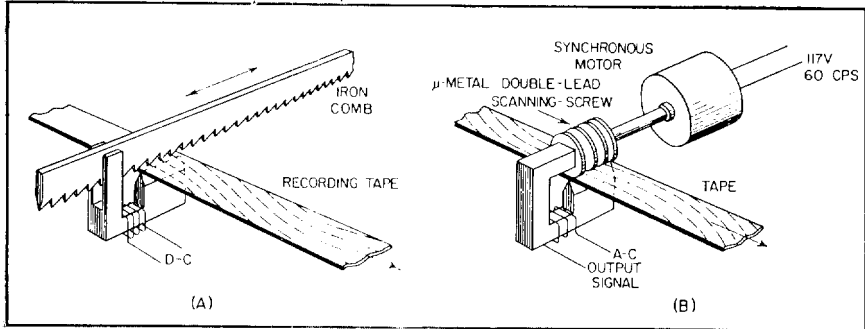


FIG. 1—Comb-shaped recording head coupled to cutting tool produces master tape for control (A); screw serves as playback head for producing control signal (B)

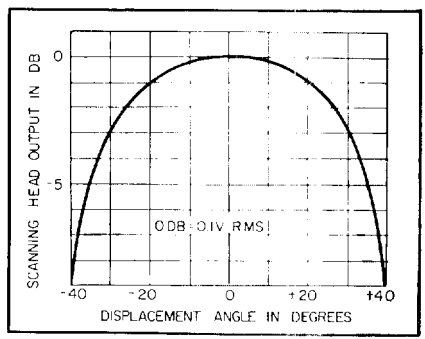
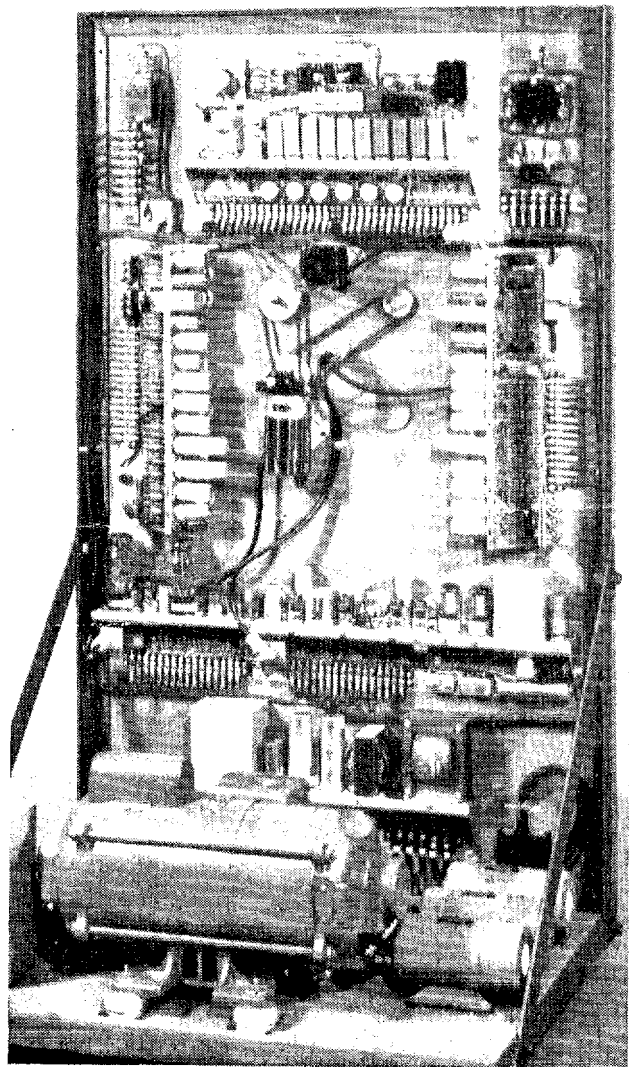
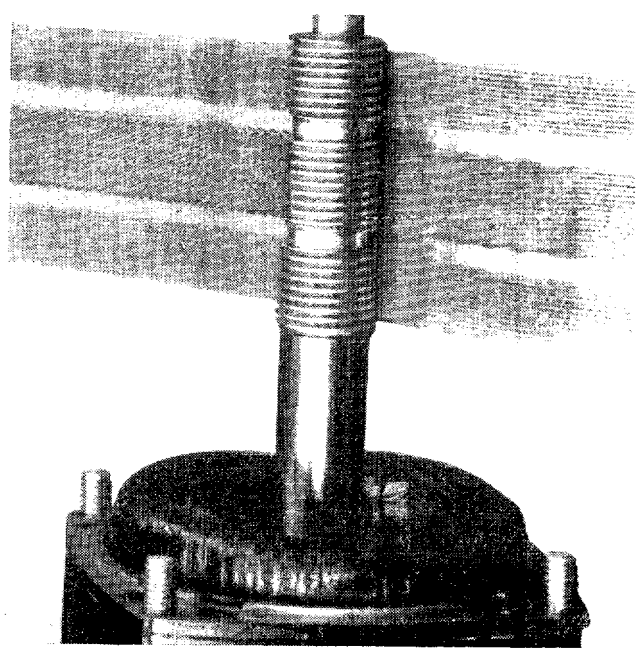
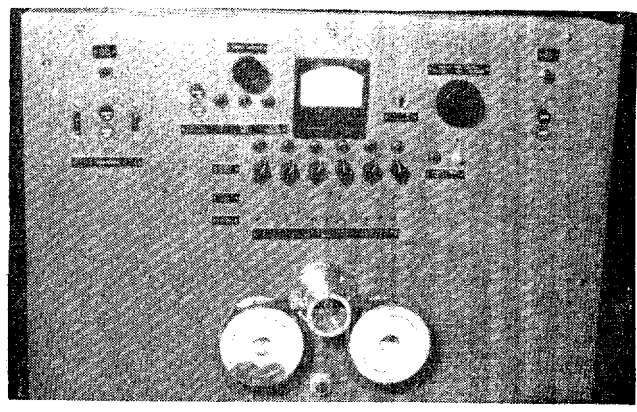


FIG. 2—Scanning-head response with zero tape velocity

Magnetic Tape Controls



THE FRONT COVER—Control panel at upper left shows tape running through primary frequency generator. Mu-metal rotor, below, reads three-channel tape which has been immersed in a solution of finely powdered iron particles to show magnetization. Rear view of the complete electronic control is shown at right

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